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ECONOMIC EFFECTS OF RESERVOIR SEDIMENTATION

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PAPERS

ECONOMIC EFFECTS OF RESERVOIR SEDIMENTATION

By William E. Corfitzen,[1] M. ASCE

Synopsis

This paper is the result of several months of study by members of the Subcommittee on Economic Effects of Reservoir Sedimentation. The subcommittee is convinced that the problem has many facets, and an ultimate satisfactory solution can be obtained only after each of these facets has been recognized, defined, and properly coordinated with others which make up the entire problem. This paper seeks to separate the elements of a problem which are of paramount importance wherever large expenditures are proposed for the construction of dams. It discusses bases for estimating sediment loads and rates of sedimentation, briefly discusses the effects of such sedimentation on uses, such as irrigation, power, municipal water supply, flood control, and navigation, and concludes with brief considerations to be observed in computing the cost of sedimentation in any given reservoir.

Elements of the Problem

More storage reservoirs probably have been created since 1925 than in any period of history. Investigations lead engineers to believe that sedimentation will limit the usefulness of most of them to less than 200 years. With dam sites limited, and construction costs advancing, planning engineers realize that a serious economic problem exists, particularly where large dams have been (or are to be) constructed, for municipal water supply, irrigation, or flood control.

In estimating the economic effects of sedimentation in any reservoir, few, if any, generalizations can be applied. Each reservoir must be analyzed in the light of the particular data applicable to that reservoir. First in the order of analysis is the anticipated rate of sedimentation. The best basis for such an estimate would be long-term records of suspended-load and bed-load measure-

Note.—Written comments are invited for publication; the last discussion should be submitted by February 1, 1951.

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ments made at, or near, the reservoir site. If such records are not available, a sampling station should be established at, or near, the site and the results correlated with those of other long-term records elsewhere on the same stream. Frequent inability to find any sampling stations serves to emphasize the urgent need for the immediate establishment of a coordinated network of stream-gaging and sediment-gaging stations on all major streams. With basic daily data the sediment load, W_d, in tons per day, may be estimated by the formula:

$$W_d = \frac{86{,}400 \times 62.4\, p\, Q}{2{,}000} \qquad (1)$$

in which Q is the daily mean flow, in cubic feet per second, and p is the percentage of sediment (by weight) expressed as a decimal. The conversion constants in Eq. 1 are 86,400 sec per day, 62.4 lb per cu ft, and 2,000 lb per ton.

Since daily load records are desirable for many sedimentation studies, they should be converted to acre-feet per year for economic studies of reservoirs. The weight of an acre-foot of sediment in place will vary with the physiographic forms and general features of surface relief that characterize different watersheds or different regions of the same watershed. The weight of deposited sediment varies from 40 lb per cu ft to more than 100 lb per cu ft. The laws of compaction as applied to reservoirs are unknown and present another field where research is urgently needed. At present the best an engineer can do is to obtain several samples of deposited material and determine the weight per cubic foot, γ_s. An estimate of the weight of an acre-foot of sediment in place, W_a, can then be obtained from the relation:

$$W_a = \frac{43{,}560\, \gamma_s}{2{,}000} = 21.78\, \gamma_s \qquad (2)$$

in which W_a is the weight of an acre-foot of sediment in place, in tons; and γ_s is the weight of a cubic foot of sediment, in pounds. The conversion constants are 43,560 cu ft per acre-ft and 2,000 lb per ton. The average annual sediment influx to a reservoir S, in acre-feet, will then be obtained from the relation:

$$S = \frac{\sum_{n=1}^{n} W_d}{\frac{n}{365}\, 21.78\, \gamma_s} = \frac{0.17 \sum_{n=1}^{n} W_d}{n\, \gamma_s} \qquad (3)$$

in which n is the number of days on which samples were taken. The conversion constant is 365 days per year.

At this point the engineer will have to determine how much of the load will pass through the reservoir and how much will be deposited in it. Depending on the size and the operating conditions of the proposed reservoir, some part of the sediment load may be transported through the basin in the form of a density current and may be discharged over the spillway or through the outlet works. If the basic data from which the estimate of sediment inflow was made did not contain bed-load data, an estimate of that load should be made now. Also of value for future use would be the determination of the sources of the sediment

retained in the basin for, as the economic studies proceed, they may indicate the desirability of undertaking remedial measures at certain upstream points to prolong the life of the proposed reservoir. At present the lack of adequate stream-flow data and of quantitative evaluation of the influence of erosion-control measures makes such a determination very difficult.

The economic life of a reservoir will depend on a number of factors, an important one being the nature of the use or uses of the impounded water, together with the relationship between such uses and the accumulating silt. Other factors involved in estimating the economic life of a reservoir are:

1. The established use pattern of the reservoir and the economic life without further controls;
2. Possible controls, their costs, their effectiveness, and their economic justification; and
3. The cost of a reservoir to replace the existing reservoir. Pertinent considerations are irrigation, power, municipal water supply, flood control, navigation, and sediment retention.

Irrigation.—Before the construction of a dam, the unregulated flow of the river provided water for the irrigation of certain lands. Complete sedimentation of the reservoir and a return to this condition might not affect the water supply. However, the loss of reservoir capacity allocated to irrigating these lands, in excess of natural flow conditions, represents a very definite monetary deficit. Although the value of the water is dependent on such uncertain factors as extent, character, and market conditions of future crops, current practice is to place a reasonable value on irrigation water depending on the locality. With such information and with the irrigation area dependent on storage known, the annual revenue from irrigation can readily be computed. From the rate of sedimentation, the engineer can estimate the number of years hence when the irrigation pool will begin to be reduced and the ultimate time when irrigation storage no longer will be possible. This is not the only loss, however. Studies have indicated that one farm family on an irrigated area supports four additional families on that and surrounding areas. Consequently, as the irrigation pool is depleted, there would naturally follow a decrease in agricultural production with an attendant decline in income to the farm family and to each dependent family. The land values of agricultural and near-by urban properties probably would decline. Such reductions in income affect the taxes that people pay and lead to the inescapable conclusion that the problem is one of national importance.

During the years when storage is being lost there exists the danger that farmers, who have made substantial investments in their lands, will plant crops beyond the availability of water to sustain growth. Consequent crop failures could be tremendous and might conceivably lead to relocating populations.

Power.—When a reservoir is put into operation, definite estimates can be made of the annual income to be derived from firm power and dump power. If sedimentation affects the minimum regulated outflow, the effect may be to decrease firm power and to increase dump power, with great loss of revenue. However, if the rate of sedimentation is known, such revenue losses may be

evaluated not only at the cost of power at the plant in question but also at the cost of replacement power which, in some instances, may be much higher.

As in the case of irrigation, there will be individuals and industries who will make investments on the assumption that power always will be available. Any decline in power not replaced from some other source will result in loss of revenue to individuals and industries and may even result in the physical relocation of industries.

Municipal Water Supply.—In addition to the actual revenue produced through the sale of water for domestic uses there are intangible benefits inherent in maintaining a continuous water supply. Inability to depend on the reservoir supply may lead to private pumping plants requiring huge expenditures. Such plants may lower the ground-water level to their own detriment and that of agriculturalists. Continuous release from a reservoir may have real value in improving the quality of river water by diluting alkali salts and in improving sanitary conditions by diluting industrial wastes and sewage.

Flood Control.—If an allocation has been made to flood control, and if sediment deposits prevent that use, valuable property below the dam may be subjected to recurrent and increasing flood damages. Beside actual damages such as those to crops, animals, buildings, and human life, a definite drop in the value of unprotected lands will follow.

Navigation.—Where reservoirs impound water for navigation, definite releases must be made at certain times of the year to provide water in channels that may be hundreds of miles below the reservoir. The value of such water lies in having it in the proper channel when required for navigation needs. In studying this use, trends in river traffic would be considered as well as attendant benefits of the reservoir—such as more stable ground water and dilution of pollution.

Sediment Retention.—The actual retention of sediment in a reservoir may have a monetary value worthy of consideration in an economic analysis. The sediment load in the stream below the dam will be decreased over a period of time as the channel adjusts itself to the new conditions. Consequently, sediments which formerly clogged canals and were deposited on fields, but are now retained in the reservoir, should no longer cause expensive maintenance. Sediment deposition in the reservoir, particularly during periods of high water, may lower treatment costs of municipal supplies diverted from the reservoir or from the river below the dam, and should lower maintenance costs on pumping equipment. There is another side to this "picture," however: The deposition of sediments in the reservoir and the subsequent release of clear water will generally cause a scour or degradation of the river bed below the dam. The removal of bed deposits by the clear water may lower the river below existing intake structures, and the material removed may be deposited elsewhere on the lower reaches of the stream. Both of these phenomena may be undesirable and costly. Under certain conditions the removal of sediment leads to an increase of algae with resulting higher costs for the treatment of public water supplies.

In addition to the foregoing considerations, it may be desirable to consider the effect of sediment on fish and wild life, recreation, scenery, value of properties bordering the reservoir, and possibly other uses applicable to a specific reservoir.

Considerations Involved in Computations of Cost

In arriving at the total cost of sedimentation of any given reservoir, certain items should be excluded if they relate to features that can be amortized. For example, it may be found that power plants, transmission lines, canal structures, and similar features which are subject to depreciation or obsolescence will be replaced one or more times during the life of the reservoir. Such structures generally are not affected by sedimentation but suffer losses from ordinary wear and tear, and from obsolescence. However, losses in features with remaining useful life but not subject to salvage, at the time they are rendered useless by sedimentation of the reservoir, would be a chargeable cost.

In regard to interest to be applied in computing justifiable expenditures to protect existing works or to provide for their replacement, two schools of thought exist. One group believes that interest (especially compound interest) should be eliminated when making computations of the costs and the benefits of conservation projects. The basic theory appears to be that the conservation of natural resources can be justified at any cost. On the other hand, there are those who hold the majority view that capital is a commodity. Capital is a commodity that is bought and sold, and the price paid for that commodity is the rate of interest. If government funds are available or must be raised by taxation, interest is not paid to any creditor, but the element of interest is pertinent nevertheless, because the government which has the money (or the citizen who pays the taxes) could lend that money at some rate of interest. The rate will depend on economic conditions existing at any given time but for most public expenditures the logical rate appears to be the current rate on long-term offerings of the United States Treasury Department.

The actual cost of reservoir sedimentation will vary depending on whether the basis adopted is the construction cost of the dam and the reservoir that are being rendered useless, or whether the basis is the replacement cost if another structure had to be built at the same or some other site. It is doubtful if engineers are ever justified in using the original construction cost in estimating sedimentation damage. If construction costs remained resonably constant, it might be allowable to use the original construction cost less any salvage of the work. For example, this approach might be adopted in arriving at sedimentation losses if the problem were to determine how much can justifiably be spent now, or over a period of years, on upstream erosion-control measures to prevent the present reservoir from becoming useless. However, some engineering economists believe that engineering construction costs will be 60% to 75% above the 1939 level for the 1950–1960 decade and that they probably will not recede to less than from 40% to 50% above 1939 costs for many years to come. On the other hand, if actual replacement storage is to be found, it must be borne in mind that the best reservoir site is the one usually selected for the first structure because that, generally, is the most economical. Almost invariably, adding to the height of an existing dam or planning the construction of a new dam at a new site will involve costs considerably in excess of those of the original structure. If replacement is necessary, the costs used should be those of the new structure; or, as an alternative to replacement costs, the future service value of the reservoir may be an acceptable measure of its worth.

Summary

In the ultimate computation of damages occasioned by sedimentation, any one of three standard methods may be used: (1) The annual cost method; (2) the present worth method; or (3) the capitalized cost method which is a variation of the present worth approach. The annual cost method is more generally used by engineers, and is probably more readily understood by business men who are accustomed to thinking in terms of annual expenditures. For large reservoirs, however, where annual utility losses are not uniform and comparisons are to be made involving conditions with and without conservation-control measures, it is doubtful if the method has any advantage over the present worth or the capitalized cost methods. Present worth is defined as the conversion of a money-time series into an equivalent single payment at some particular date. For convenience, the present date is generally used. Capitalized cost refers to that sum of money, the future interest on which will provide for restoring the structure in question at specified intervals indefinitely.

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